

## **VARIABLE-BANDWIDTH MULTI-GRANULARITY OPTICAL ADD/DROP NETWORK**

### **TECHNICAL FIELD OF THE INVENTION**

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This invention relates generally to optical add/drop networks and, more particularly, to a method and apparatus for implementing a variable-bandwidth multi-granularity optical add/drop multiplex network.

### **10 BACKGROUND OF THE INVENTION**

In the design and implementation of optical transparent networks, efficient utilization of bandwidth becomes challenging due to traffic demands with different end-to-end bandwidth requirements and data rates that are likely to change as the offered services change. In today's optical networks, however, since optical add-drop multiplexers (OADMs) are designed with fixed channel bandwidth, they do not provide for the efficient utilization of bandwidth. The fixed channel bandwidth OADM results in two potential problems: 1) low spectral efficiency for low-rate signals, and 2) when data rate is increased beyond the available channel bandwidth the OADM has to be replaced.

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Prior techniques only support single data rate [1]-[5]. However, none of these prior techniques have addressed the data rate upgrade issue.

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What is desired is a variable bandwidth OADM to satisfy customer requirements, reduce the cost of data rate upgrade, and to enable high-bandwidth efficiency at various data rates. The variable-bandwidth issue in a 2 x 2 wavelength-selective cross connect was addressed in Ref. [6].

## SUMMARY OF THE INVENTION

In accordance with the present invention, we disclose a method and apparatus for implementing a variable bandwidth hierarchical OADM to handle different data rates. This is achieved by using an OADM apparatus including one or more variable-bandwidth wavelength OADMs connected in parallel to a waveband OADM. The wavelength OADM combines multiple adjacent channels with fine granularity to form a variable-bandwidth device that can more efficiently accommodate channel bandwidth increases/decreases for data rate upgrade/downgrades. Furthermore, to reduce the control elements associated with the fine granularity, the waveband OADM provides coarse granularity for bundled traffic sharing the same paths. The waveband and wavelength to be passed, dropped, and added by the hierarchical OADM apparatus are all electronically selectable, hence no hardware modification is needed when the data rate is changed. The use of a coarse granularity waveband OADM and fine granularity wavelength OADM enables our hierarchical OADM apparatus and method to provide a variable-bandwidth multi-granularity add/drop capability. The waveband OADM reduces the control complexity associated with the fine granularity wavelength OADM and provides coarse granularity for bundled traffic with the same paths. Our hierarchical OADM does not require a fiber switch fabric as needed in prior proposed multi-granularity cross connect with cascaded configuration.

More particularly, our hierarchical OADM apparatus comprises

a coupler for receiving a multi-wavelength input optical signal at an input port of the OADM apparatus and coupling a first signal portion to a waveband OADM and a second signal portion to a variable-bandwidth wavelength OADM;

the waveband OADM for

receiving the first signal portion at a first input port;

selectively passing one or more wavebands of the multi-wavelength optical signal,

outputting the non-passed wavelength bands at a drop port, and  
receiving a second input optical signal at an add port which is combined with  
the passed wavebands to form a first output signal;

- 5 the variable-bandwidth wavelength OADM, connected in parallel with the waveband  
OADM, for  
receiving the second signal portion at a second input port;  
providing variable bandwidth by selectively passing one or more wavelengths  
of a selected waveband of the multi-wavelength optical signal,  
10 outputting the non-passed wavelengths at a drop port, and  
receiving a third input optical signal at an add port which is combined with the  
passed wavelength channels of the multi-wavelength optical signal to form a second  
output signal; and
- 15 a combiner for combining the first and second output signals to form an OADM  
apparatus output signal.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

- 20 The present invention will be more fully appreciated by consideration of the  
following Detailed Description, which should be read in light of the accompanying  
drawing in which:

Fig. 1 illustrates a blocker type OADM with two filters operating in  
25 complementary mode.

Fig. 2 illustrates, in accordance with the present invention, a block diagram of  
our hierarchical OADM including a waveband blocker-filter type OADM and one or  
more wavelength blocker-filter type OADMs that together provide a multi-granularity  
30 optical add/drop capability.

Figs. 3 illustrates the variable-bandwidth needed to handle different data rates.

Fig. 4A illustratively shows the pass and drop signals of a waveband OADM  
5 and a wavelength OADM when the drop signal has a bandwidth that is less than a  
waveband OADM bandwidth.

Fig. 4B illustratively shows the pass and drop signals of the waveband OADM  
and wavelength OADM when the drop signal has a bandwidth that is more than a  
10 waveband OADM bandwidth.

Fig. 5 shows an illustrative implementation of a waveband OADM.

15 Fig. 6 shows an illustrative implementation of a wavelength OADM.

In the following description, identical element designations in different figures  
represent identical elements. Additionally in the element designations, the first digit  
refers to the figure in which that element is first located (e.g., 101 is first located in Fig.  
20 1).

## DETAILED DESCRIPTION

With reference to Fig. 1, there is shown an illustrative diagram of a variable-  
bandwidth blocker-type optical add-drop multiplexer (OADM). The blocker type  
25 OADM includes two dynamic filters 101 and 102 that each has a controllable variable  
bandwidth and which operate in complementary modes. The input signal IN, shown as  
110, is split by a 50% coupler 103, which couples signals to PASS dynamic filter 101  
and a DROP dynamic filter 102. The signal outputted from the Drop filter 102, shown  
as 111, is complementary to the output signal, shown as 112, from the PASS filter 101.  
30 While the coupler 103 is described as a 50% coupler, it should be understood that a  
coupler that does not equally split the signal may be utilized. In such a situation, an

attenuator 105 or 106 would be used to equalize the signal levels to be combined in add coupler 104. Note the drop filter 102 can also be in the form of a power splitter with tunable filters. The signal from PASS filter 101 is combined with the ADD signal 113 using the add coupler 104 to form the output signal OUT from the OADM. The ADD  
5 signal may include some or all of the dropped wavelengths shown in DROP signal 111.

To reduce the control complexity, bundling of wavelengths along the same optical path in a network and optical bypassing of through traffic is an effective approach to reducing node complexity, considering that most traffic (about 75%) is  
10 through traffic [1].

Fig. 2 illustrates, in accordance with the present invention, a block diagram of our hierarchical OADM node 260 architecture that has two OADM layers in parallel, which together provide a multi-granularity optical add/drop capability. The first layer  
15 includes a waveband blocker-filter type OADM 200 and the second layer includes one or more wavelength blocker-filter type OADMs 210, 220. If there are N wavelength OADMs 220, then the total splitting ratio is  $2 \times (1+N)$ , the extra coupler outputs connecting to the wavelength OADMs 220. Alternatively, instead of using a higher port-count coupler, one could use a band demultiplexer before the wavelength OADMs  
20 and a band multiplexer afterwards. The band demultiplexer/multiplexer would route each band to a different wavelength OADM. The wavelength OADM(s) 210, 220 each provides variable bandwidth with fine granularity, while the waveband OADM 200 provides coarse granularity to reduce control elements and simplifies network management. In another embodiment, the waveband OADM 200 may be operated as a  
25 variable-bandwidth OADM to provide greater variable-bandwidth capability to the OADM node 260. Incoming signals IN are power-split, in splitter 230, and fed into the waveband 200 and wavelength 210 OADMs, each operating in a broadcast and select manner based on blocker filters. As mentioned above, if the hierarchical OADM node 260 includes a second wavelength blocker-filter type OADM 220, then the splitter 230  
30 must divide the input signal IN into three equal parts.

With reference to Fig. 3, the wavelength OADM 210 provides adjustable bandwidths as fine as 12.5 GHz indicated as 301, and as coarse as 400 GHz indicated as 302, which is the total available bandwidth of the wavelength OADM 210. The waveband OADM is selected to have a 400-GHz bandwidth, equal to thirty two 12.5 GHz wavelength channels. Note the fine and coarse bandwidth values used here are for illustration purpose, other variations can apply. Using this technique, an illustrative C band of 4 THz can be handled by a waveband OADM 200 having ten 400 GHz bands and a wavelength OADM 210 having thirty-two 12.5 GHz wavelength channels. This compares to an alternative possible technique of handling 4 THz using a wavelength OADM having 320 controllable 12.5 GHz wavelength elements, which increases control complexity. Plus, such a device is not available yet. Our hierarchical OADM node 260 architecture also supports the common data rates such as 10-Gb/s (using two 12.5 GHz channel), 40-Gb/s (using eight 12.5 GHz channels), and 160-Gb/s (using thirty two 12.5 GHz channels). The above assumes that the data rate in Gb/s utilizes only 40 percent of the channel width in GHz. Thus our adjustable-bandwidth hierarchical OADM node 260 architecture supports multiple data rates of 10 Gb/s, 40 Gb/s, and 160 Gb/s, with the same spectral efficiency. While the present invention has been described with respect to using the standard channel size and separation, it should be noted that our hierarchical OADM node 260 architecture could be equally applied to other channel sizes and separations.

As previously noted, prior techniques utilized multi-stage switching at the wavelength and waveband levels to reduce the number of connection ports [1] – [5]. By using our hierarchical OADM 260 node architecture that has waveband and wavelength OADM layers in parallel and using blocker-type devices to provide a multi-granularity optical add/drop capability, we have eliminated the need for a switch fabric.

Returning to Fig. 2, once bundled traffic streams fill a waveband, they are then passed through the waveband OADM 200. The coarse granularity in the waveband OADM 200 helps to reduce the number of connection and control ports, and therefore the node complexity that is seen in the wavelength OADM 210, while the wavelength

OADM 210 provides flexible bandwidths with fine granularity. Unlike the prior  $N \times N$  wavelength selective type switch fabric as used in multi-granularity optical cross connect, our parallel architecture hierarchical OADM node 260 is based on blocker type filters for the wavelength and waveband OADMs. Therefore no switch fabric is  
5 needed at the waveband/wavelength level. In addition, our parallel structure also reduces the signal degradation since there is no cascading of filters. As will be discussed, there could be one or more wavelength OADMs 210, 220 attached with a waveband OADM 200, depending on the traffic pattern. A controller unit 250 coordinates the operation of waveband OADM 200 and wavelength OADMs 210, 220,  
10 i.e., to insure that if a given wavelength is to be dropped through a wavelength OADM 210, the corresponding waveband in the waveband OADM 200 should be blocked. Note in the following description the term “blocked” is used to refer to wavelengths or wavebands that are “not passed” by an OADM.

15 With reference to Fig. 4A and 4B we describe illustrative operational examples of OADM node 260 and how controller 250 coordinates the operations of waveband OADM 200 and wavelength OADMs 210, 220. With joint reference to Figs. 2 and 4A, we first assume that OADM node 260 receives a WDM signal, IN, over an optical facility. The WDM signal, shown as waveform 410, includes all channels C1 - C32 in  
20 all Bands B1 – B10 and we assume that OADM node 260 is to drop three 12.5 GHz wavelength channels C1-C3 of band B1. This example illustrates the fine granularity feature of our OADM node 260. We also assume that one new channel C1 is to be added by add unit 213. The channel drop and add information is received by controller 250 of OADM 260 in the standard manner, from control information embedded in the  
25 WDM signal or received over a separate signaling facility. While controller 250 is shown as part of OADM node 260, it could also be part of a separate control unit that may control other OADM nodes. Since waveband OADM 200 and wavelength OADM unit 210 are electronically controllable by controller 250 (as will be described in later paragraphs), real-time control can be exercised in response to real time network control  
30 information.

As shown by waveform 420, in response to the drop channels C1 – C3 of band B1 control information, controller 250 signals waveband blocker 201 of OADM 200 to block band B1 and to pass bands B2 – B10. As shown by waveform 430, controller 250 also signals drop unit 202 of OADM 200 to block bands B1 – B10. Controller 250 also signals wavelength blocker 211 of OADM 210 to block channels C1 – C3 and to pass channels C4 – C32, as shown by waveform 440. Controller 250 also signals drop unit 212 to pass (i.e., drop) channels C1 – C3 at the drop port and to block channels C4 – C32, as shown by waveform 450. The resulting OUT signal at the output port of OADM node 260, which combines the signals from waveband blocker 201, wavelength blocker 211, and from add unit 213, is shown by waveform 460. As waveform 460 shows for OADM node 260, the OUT signal includes the ADD signal C1 (from add unit 203) and C4 – C32 of band B1 (from wavelength blocker 211) and bands B2 – B10 (from waveband blocker 201) and no signal from add unit 203. As waveform 470 shows, for OADM node 260, the DROP signal includes only channels C1-C3 of band B1, since no bands were dropped by waveband OADM 200. Note that for OADM node 260, if we ignore the ADD signal channel C1, the OUT signal 460 is complementary to the DROP signal 470 as required.

It should be noted that the waveband OADM 210 enables any one or more channels, either contiguous or separated channels within one band to be dropped. If one or more channels, either contiguous or separated channels within another band were to be to be dropped another wavelength OADM unit 220 would be used. The number of different wavebands, B1 – B10, that have one or more channels to be dropped will determine the number of wavelength OADMs (210, 220, etc.) needed (one wavelength OADM for each separate band having one or more wavelength channels to be dropped). As noted previously, to reduce the control complexity and the number of wavelength OADMs needed, bundling of wavelengths along the same optical path in a network and optical bypassing of through traffic should be utilized.

With joint reference to Figs. 2 and 4B, for this example we again assume that OADM node 260 receives a WDM signal, IN, shown as waveform 410a, includes all



channels C1 - C32 in all Bands B1 – B10. In this example we illustrate and discuss the coarse waveband and fine wavelength granularity feature of the invention. We assume that OADM node 260 is to drop channels C30 – C32 in band B1, all of band B2, and channels C1-C4 of band B3 are to be dropped. In this example, controller 250 sends  
5 control signals to enable the wavelength OADM 210 and 220 to be associated, with bands B1 and B3, respectively.

Again, the channel drop and add information is received by controller 250 of OADM 260 in the standard manner. As shown by waveform 420a, in response to the  
10 drop channel control information, controller 250 signals waveband blocker 201 of OADM 200 to block bands B1 – B3 and to pass bands B4 – B10. As shown by waveform 430a, controller 250 also signals drop unit 202 of OADM 200 to pass (drop) band B2 and to block bands B1, B3 – B10. As shown by waveform 440a, controller 250 signals wavelength blocker 211 of OADM 210 to block channels C1 – C4 and pass  
15 channels C5 – C32 of band B3. As shown by waveform 450a, controller 250 also signals drop unit 212 to drop (pass) channels C1-C4 to the drop port and to block channels C5 – C32 of band B3. As shown by waveform 440b, controller 250 also signals the wavelength blocker (not shown) of OADM 220 to pass channels C1 – C29 and block channels C29 – C32 of band B1. As shown by waveform 450b, controller  
20 250 also signals the drop unit (not shown) of OADM 220 to drop (pass) channels C30-C32 and block channels C1 – C29.

Shown by waveform 460a is the resulting signal at the output OUT port of OADM node 260, which is a combination of the signals from waveband OADM 200  
25 (blocker 201), wavelength OADM 210 (blocker 211), and wavelength OADM 220 (blocker and add unit not shown). As shown, waveform 460a includes existing bands B4 – B10 (from the waveband blocker 201 of OADM 200), and C1 – C29 of band B1 (from the wavelength blocker 211 in the wavelength OADM 210), and existing channels C5- C32 (from the wavelength blocker of OADM 220). As shown by waveform 470a,  
30 the dropped channels include C30-C32 of band B1, the dropped band B2, and the

dropped channels C1 – C4 of band B3. Again, note that for OADM node 260 the OUT signal 460 is complementary to the DROP signal 470 as required.

5        With reference to Fig. 5, we describe the implementation of an illustrative waveband OADM 200. This is described in US Patent 6,266,460, “Large-channel-count programmable wavelength add-drop” by C. R. Doerr. Both the waveband blocker 201 and drop unit 202 are each implemented using a planar waveguide add-drop filter having 400 GHz granularity. In the waveband blocker 201 only the input port 502 and  
10    output (through) port 503 of the device 501 are used so it behaves as a blocker filter. It covers 32 nm, which in our application is divided to 10 wavebands B1 – B10, each having 400-GHz bandwidth. Switches 504 are used to dynamically control the selected bands from the input port 502 that are to be passed through to the output port 503 via circulator 504. The illustrative drop unit 202 utilizes the input port 502 and the drop  
15    ports 503 of the planar waveguide add-drop filter. The add unit 203 typically includes a WDM multiplexer for each band to be added. While the drop unit 202 was described as using a wavelength demultiplexer, it should be noted that power splitter with one or more filters may also be utilized. The latter approach may be desirable when only one or a few wavelengths are to be dropped. Additionally, the add unit 203 may also be  
20    implemented using a simple power combiner.

      The planar waveguide add-drop filter used in both the waveband blocker 201 and drop unit 202 may be implemented as described in the article entitled “40 – Wavelength Add-Drop Filter” by C. R. Doerr et al, IEEE Photonics Tech. Letters, Vol.  
25    11, No. 11, November 1999, pages 1437 – 1439, which is incorporated by reference herein.

      With reference to Fig. 6, we describe the implementation of an illustrative wavelength OADM, e.g., 210. Both the wavelength blocker 211 and drop unit 212 are  
30    implemented using a blocker type filter that supports different bandwidths in add-drop. In our embodiment, a micro electro-mechanical switch (MEMS) based blocker filter

with 32 continuous channels, and the channel spacing designed to be 12.5 GHz is used. The MEMS based blocker filter may be implemented as described in the article entitled “High –dynamic Range Channelized MEMS Equalizing Filter” by D. T. Neilson et al, OFC 2002, page 586-588, which is incorporated by reference herein.

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The grating 605 is used to select the waveband B1 – B10 at which the input wavelength blocker 211 is to be used. A control signal from controller 250 selects the angle 605 and hence the selected waveband. Only the input WDM signal of the selected waveband will be reflected to lens 603. The input WDM signals are received at input port 601, passes through circulator 602 and lens 603 directs the signal to grating 605. The grating 605 demultiplexes the WDM signal into its components wavelength channels (32 in our example) and directs these back through lens 603 to MEMS chip 606. The MEMS chip 606 is also responsive to a control signal from controller 250 to select channels that are to be blocked. MEMS 606 does not reflect the blocked channels. The channels to be passed are reflected back by MEMS 606 through lens 603, grating 605, lens 603, and circulator 602 to output port 607. The drop unit 212 operates in a similar manner, except that the dropped channels are reflected back by MEMS chip 606 to the port 607, which serves as a drop port. Again the MEMS chip 606 of drop unit 212 is responsive to a control signal from controller 250 to select channels that are to be dropped.

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While our example of the wavelength blocker 211 and drop unit 212 of wavelength OADM 210 uses 32 channels, any arbitrary number of neighboring channels can be combined to form a new, wider wavelength channel to support higher data rates. The total bandwidth of the wavelength OADM is 400 GHz to fill a waveband. Thus under control of controller 250, data-rate upgrade can be realized electronically without hardware modification in the OADM node 260. The controller 250 controls the selection of the waveband handled by waveband OADM 200 and wavelength OADM 210 and controls the selection of the wavelengths by wavelength OADM 210 (and any additional wavelength OADMs, e.g., 220 utilized).

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The wavelength blocker has a free-spectral range smaller than the full span covered by the waveband device. In such a case, one could use the band demultiplexer/multiplexer architecture to improve out-of-band suppression ratio described earlier.

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Various modifications of this invention will occur to those skilled in the art. Nevertheless all deviations from the specific teachings of this specification that basically rely upon the principles and their equivalents through which the art has been  
10 advanced are properly considered within the scope of the invention as described and claimed.

## REFERENCES

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- [6]. C.R. Doerr et al., "2 x 2 wavelength-selective cross connect capable of switching 128 channels in sets of eight," *IEEE Photonics Technology Letters*, March, 2002, pp 387-389